# Chapter 10
# Blockchain-Based IoT for Precision Agriculture: Applications, Research Challenges, and Future Directions

**Okacha Amraouy**
https://orcid.org/0000-0001-7913-5132
*Faulty of Sciences, Sidi Mohamed Ben Abdellah University, Morocco*

**Yassine Boukhali**
https://orcid.org/0000-0002-9173-7424
*Faulty of Sciences, Sidi Mohamed Ben Abdellah University, Morocco*

**Aziz Bouazi**
*Moulay Ismail University, Morocco*

**Mohammed Nabil Kabbaj**
https://orcid.org/0000-0002-6478-1892
*Faulty of Sciences, Sidi Mohamed Ben Abdellah University, Morocco*

**Mohammed Benbrahim**
*Faulty of Sciences, Sidi Mohamed Ben Abdellah University, Morocco*

## ABSTRACT

*In recent years, IoT has been increasingly applied in agriculture to transform traditional farming practices into smart and precision agriculture (PA) that are more efficient, productive, and sustainable. However, its implementation in agriculture faces several challenges, including network coverage, reliability, lack of flexibility, and scalability. To address these challenges, current research has focused on developing new communication protocols and technologies, along with several IoT architectural design patterns, especially those based on SOA, which play a crucial role in designing service-oriented solutions. This chapter presents comprehensive and impactful solutions for blockchain-based IoT applications in PA. It proposes novel models combining IoT, blockchain, fog and cloud computing for the development of decentralized applications with independent, autonomous, and interoperable functionalities and services based on the SOA approach. Also, technical challenges, research directions, and the recent advances towards an optimized blockchain-based IoT ecosystem for PA are presented.*

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## INTRODUCTION

There is a large number of research in the literature that recognizes the importance of using emerging advanced technologies and data-driven solutions in Precision Agriculture (PA) (Torky & Hassanein, 2020; W. Lin et al., 2020; R. Tanwar et al., 2023). PA refers to a range of tools, systems, and techniques used in modern farming practices, based on the use of Information and Communications Technology (ICT), global positioning system technology, robotics and automation technologies, variable rate technology, satellite technology, geographical information system and remote sensing. These technologies aim to enhance performance, efficiency, productivity, and security across all agricultural functions and services by implementing flexible, intelligent, and precision-controlled systems (Khanal, Fulton, & Shearer, 2017). Today, PA started to rely upon IoT (V. K. Quy et al., 2022), wireless sensor and actuator networks (M. Sultan et al., 2023; Singh & Sharma, 2022; Jihani, Kabbaj, & Benbrahim, 2023), weather monitoring systems, wireless networks (Feng, Yan, & Liu, 2019), smart irrigation and fertilization systems (E. A. Abioye et al., 2020; R. L. Ray et al., 2022; N. Lin et al., 2020), drones (V. Puri et al., 2017; Mogili & Deepak, 2018), Fog/Edge computing (E. Guardo et al., 2018), cloud computing (Ahmed, De, & Hussain, 2018), SOA (Khanna & Kaur, 2019), virtualization and containerization (C. Núñez-Gómez et al., 2021), Artificial Intelligence (AI) (K. Jha et al., 2019), big data analytics (Akhter & Sofi, 2022), and BlockChain (BC) (Y.-P. Lin et al., 2017). Based on these technologies, it becomes possible to create a next-generation internet of smart farming as the backbone of modern agricultural systems and processes. Also, forecasting methods/models and predictive analytic software systems leverage agricultural data, employing data analysis techniques and advanced algorithms to make predictions concerning future outcomes or trends. These predictions are derived from a combination of historical and Real-Time (RT) data, allowing for more accurate and informed decision-making in PA. Thus, advancements in optimization, prediction, and control algorithms have a significant impact on PA (F. Jamil et al., 2022). Prediction algorithms are used to analyze sensing data collected from various sources such as weather stations, satellite imagery, drones, soil sensors, and crop monitoring systems. By applying Machine Learning (ML) and statistical techniques, prediction algorithms can identify hidden patterns, correlations, and trends in the data (K. Jha et al., 2019). They enable farmers to make informed decisions about irrigation scheduling, fertilizer application, disease detection, yield estimation, and pest control. By predicting future outcomes, farmers can optimize their resource allocation, minimize risks, and maximize productivity. Similarly, optimization algorithms process sensing data and other relevant parameters to determine optimal strategies for various agricultural practices. These algorithms utilize mathematical models and optimization techniques to maximize profits or minimize losses. For example, they can optimize crop planting patterns, determine the ideal timing and quantity of irrigation and fertilization, and optimize resource allocation across different fields or crops. Likewise, control algorithms build upon the outputs of prediction and optimization algorithms to implement automated control mechanisms in PA. These algorithms utilize optimal parameters and strategies determined by the optimization algorithms to effectively control actuating devices. Besides these advancements, Decision Support Systems (DSS), data mining, and data analysis, along with the use of web-based DSS, have become significant techniques in managing services in PA. (Z. Zhai et al., 2020). Furthermore, various irrigation decision models have been developed to support farmers in making optimal irrigation decisions (Car, 2018; H. M. Abd El Baki et al., 2018; E. Bwambale et al., 2023; E. A. Abioye et al., 2022). These models take into account factors such as soil moisture levels, weather conditions, crop water requirements, and irrigation system efficiency. By incorporating these models into DDS, farmers can determine the most appropriate ir-

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